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Laser Induced Ignition with Resonant Multiphoton Absorption in Oxygen

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Ultraviolet Laser Induced Ignition Using Resonant Enhanced Multiphoton Ionization

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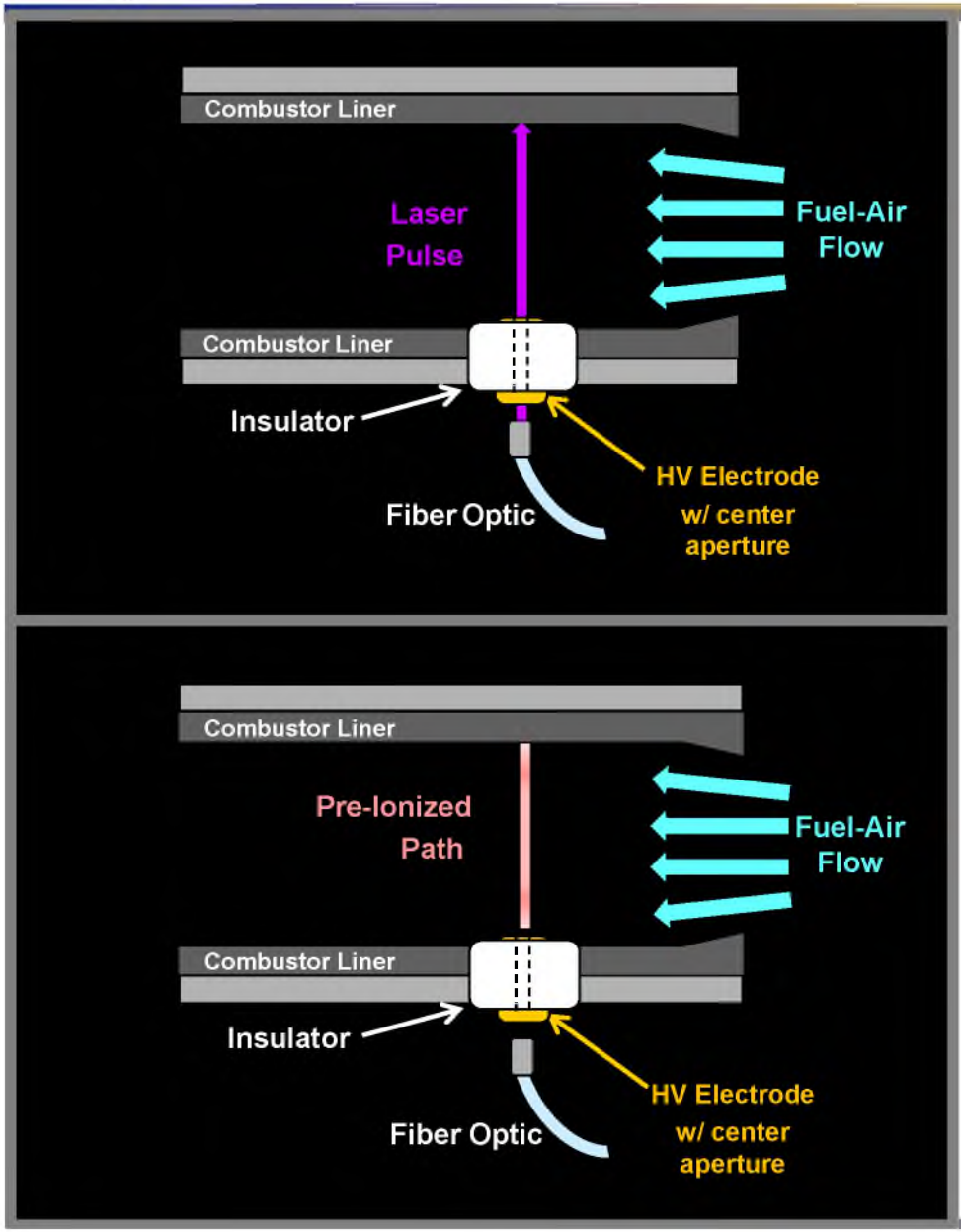
Abstract

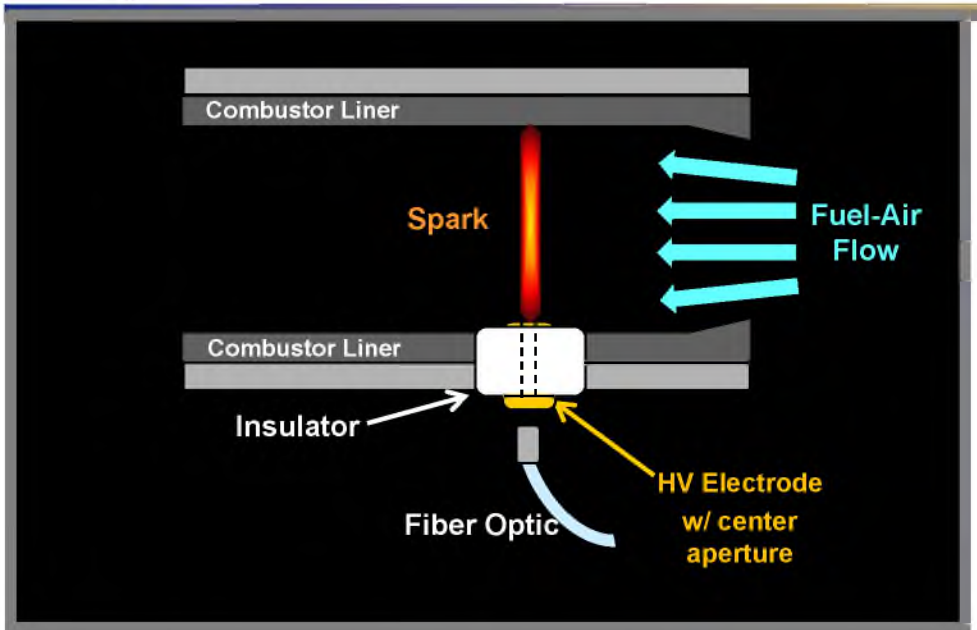
A novel resonant laser-induced breakdown scheme has been demonstrated to provide precision guidance of spark formation within an air flow and has been further demonstrated in resonant laser-induced ignition of a moderate-speed air-propane flow. This scheme could potentially provide combustion ignition with a laser trigger within a high-voltage gap using a compact laser source with fiber coupling. The laser scheme involves resonant enhanced multiphoton ionization (REMPI) in molecular oxygen to generate a pre-ionized micro-plasma path between high voltage electrodes and thus guide the ignition spark through fuel-rich areas of the air-fuel flow. Results of this study include high speed photography of flame ignition in an air-propane flow, showing the spatial and temporal evolution of the laser-induced arc and plasma kernel leading to combustion and full flame.

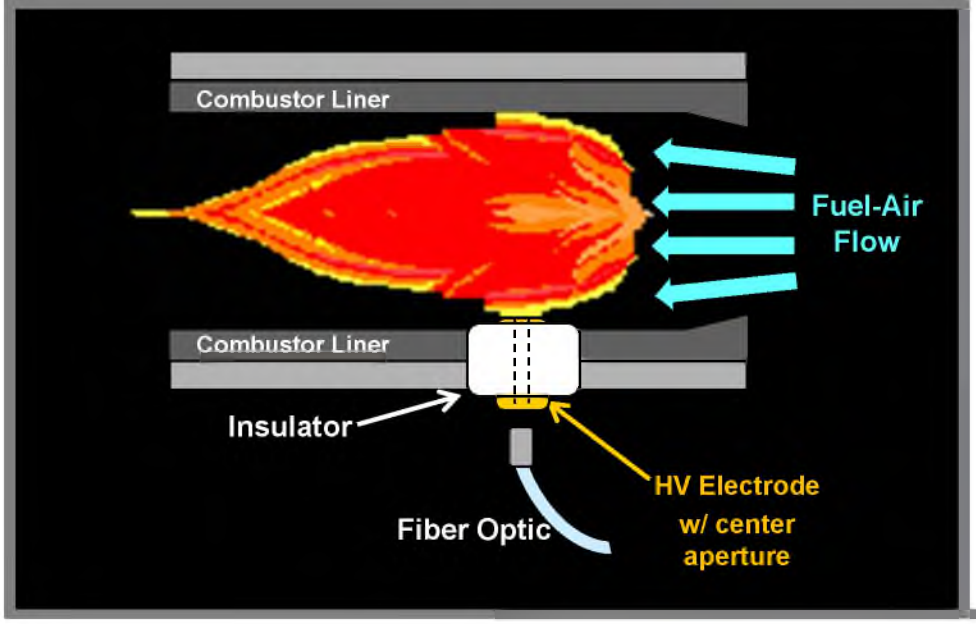
Laser-Induced Ignition Concept



- Laser pulse delivered via fiber optic into ignition chamber
- Laser at 287.5 nm generates resonant-enhanced multiphoton ionization (REMPI) in oxygen
- REMPI creates creates pre-ionized path extending across chamber along laser path

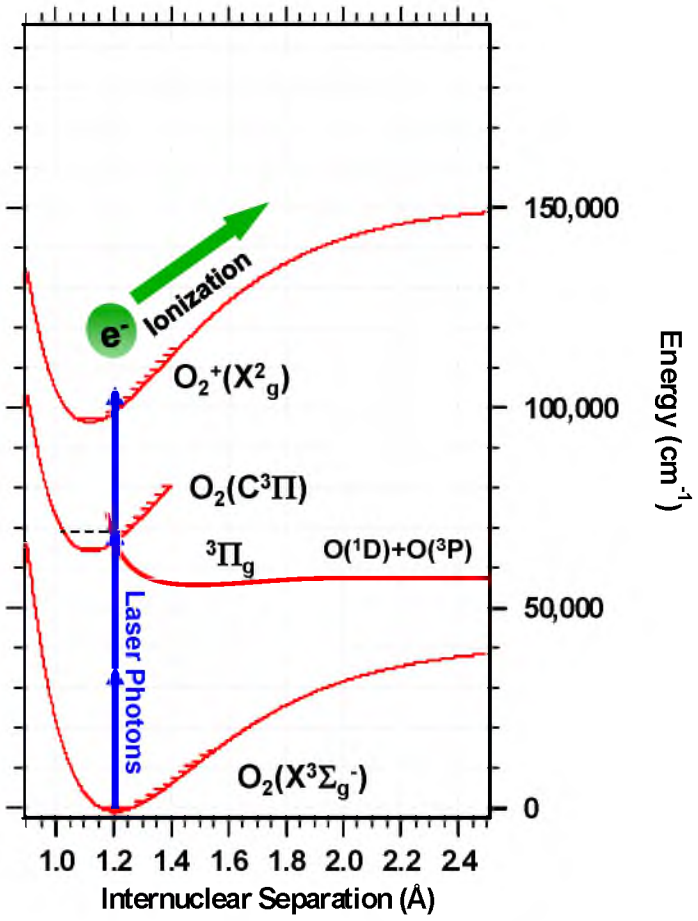
Laser-Induced Ignition Concept





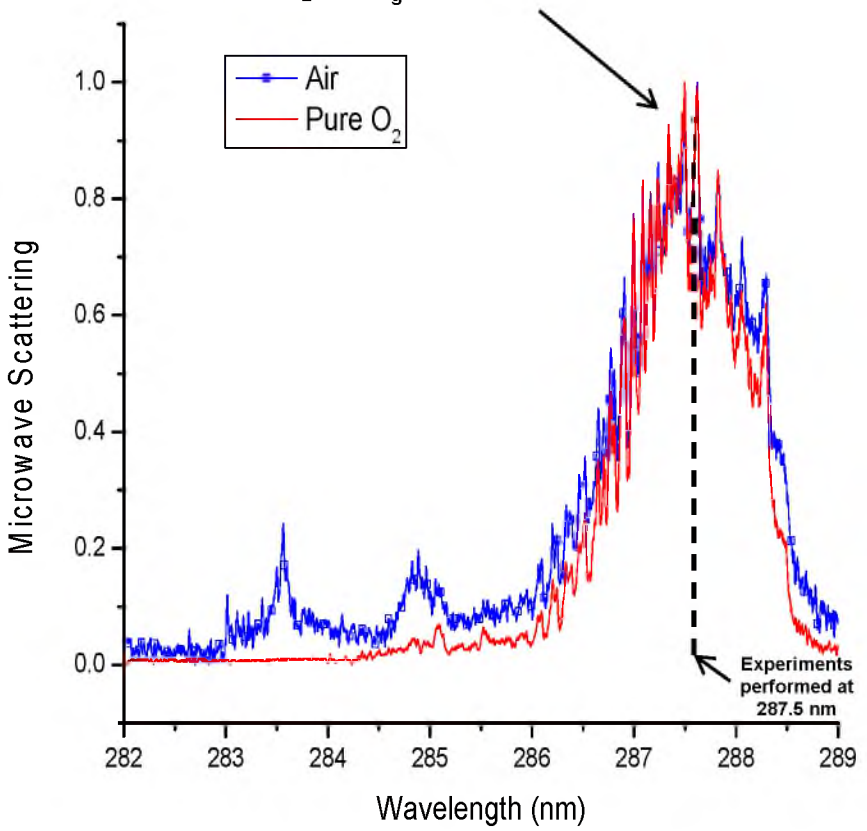
- High voltage applied and spark is guided along pre-ionized path
- Spark ignites fuel-air flow
- High reliability of ignition within central fuel-rich region

Why use REMPI at 287.5 nm?



- O_2 REMPI Process Induces Breakdown in Atmospheric Air

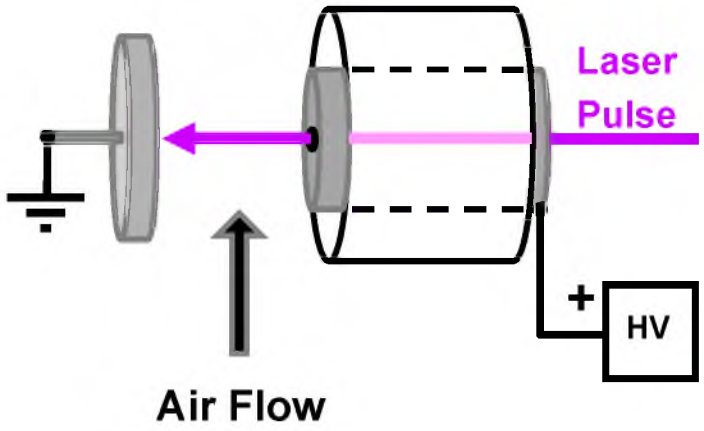
- Strong multi-photon ionization corresponding to O_2 ($C\ ^3\Pi_g$, v=2) resonant intermediate



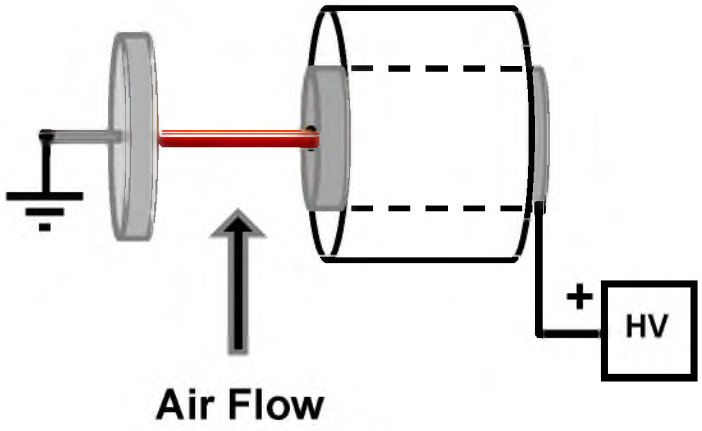
Wu, Zhang, and Adams, *Chem. Phys. Lett.* submitted (2011)

- Microwave scattering indicates a high level of photoionization from this O_2 REMPI band

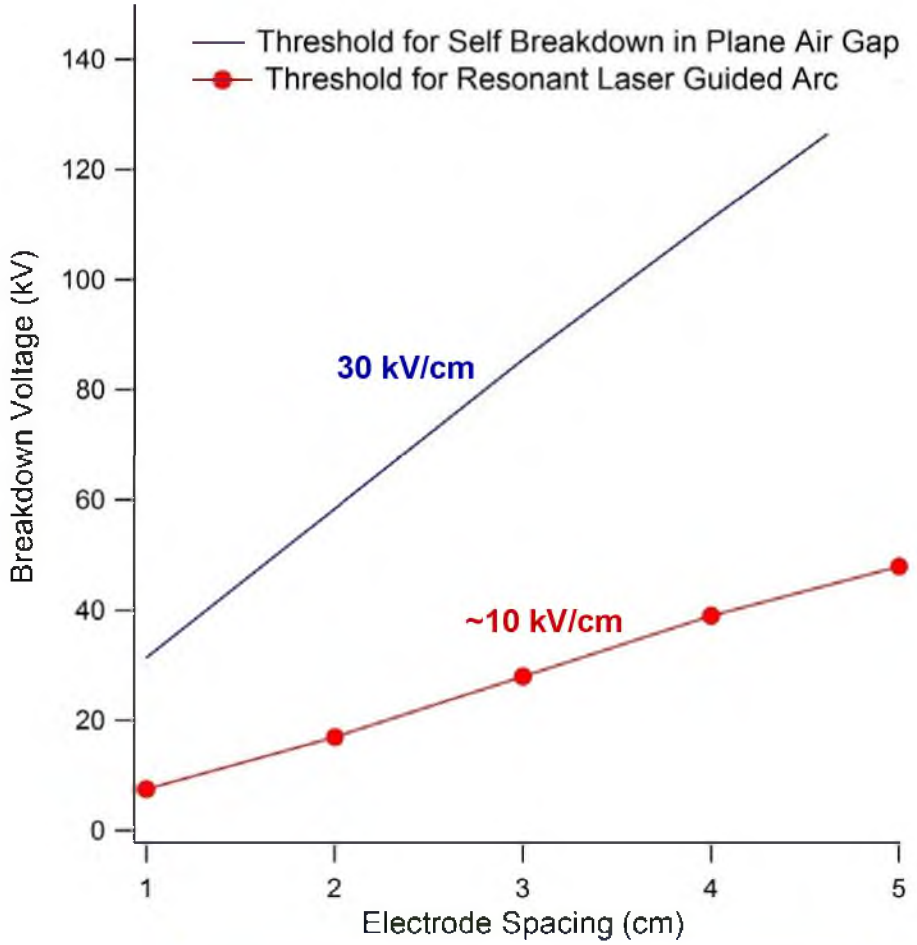
Volume Ionization in Air: O_2 REMPI with Ultraviolet Laser



- Laser sent through aperture in high voltage electrode

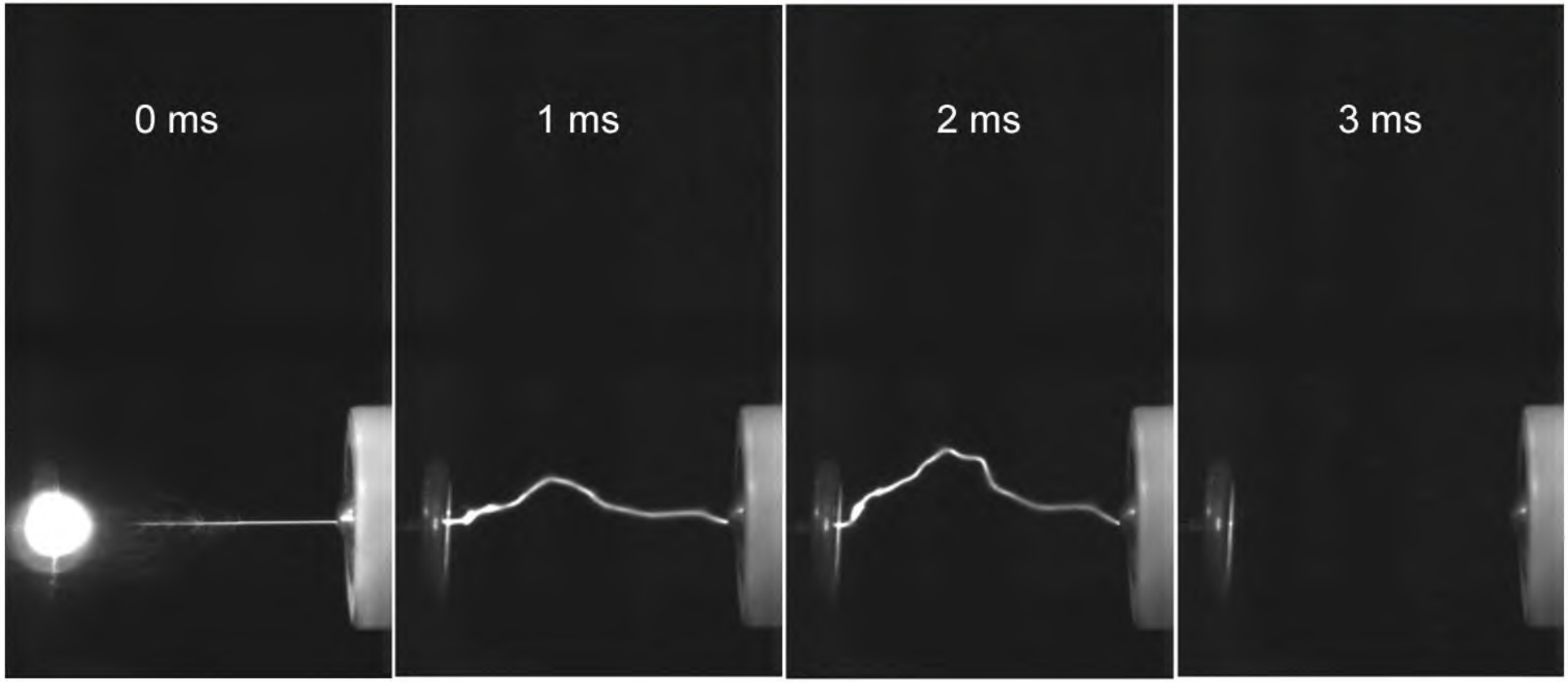


- Breakdown and spark follows laser pulse along pre-ionized path



- Laser-induced threshold is ~1/3 of theoretical air self-breakdown

High Speed Images of REMPI Laser Induced Arc in Air Flow



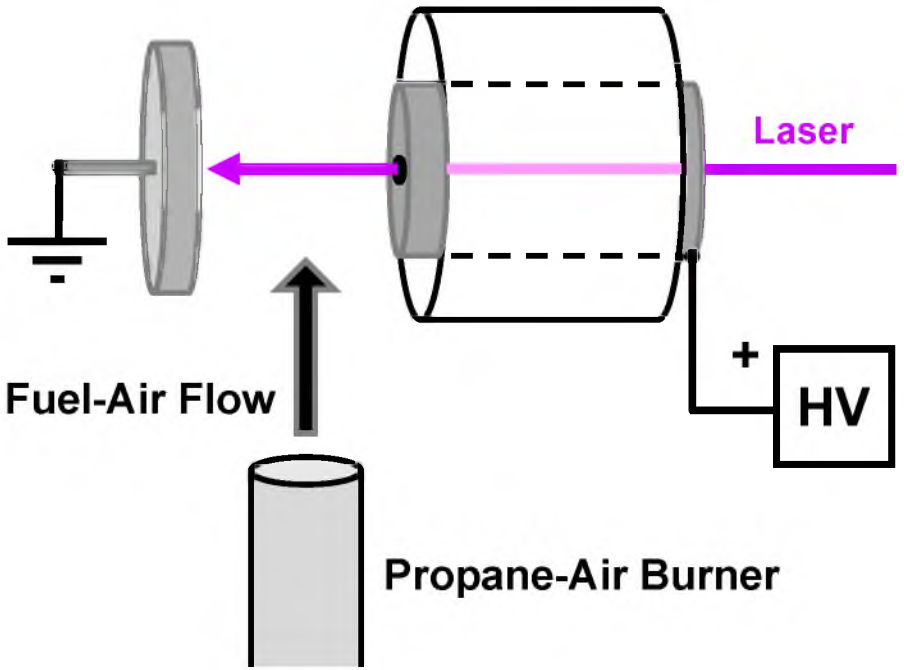
Initial arc along laser path

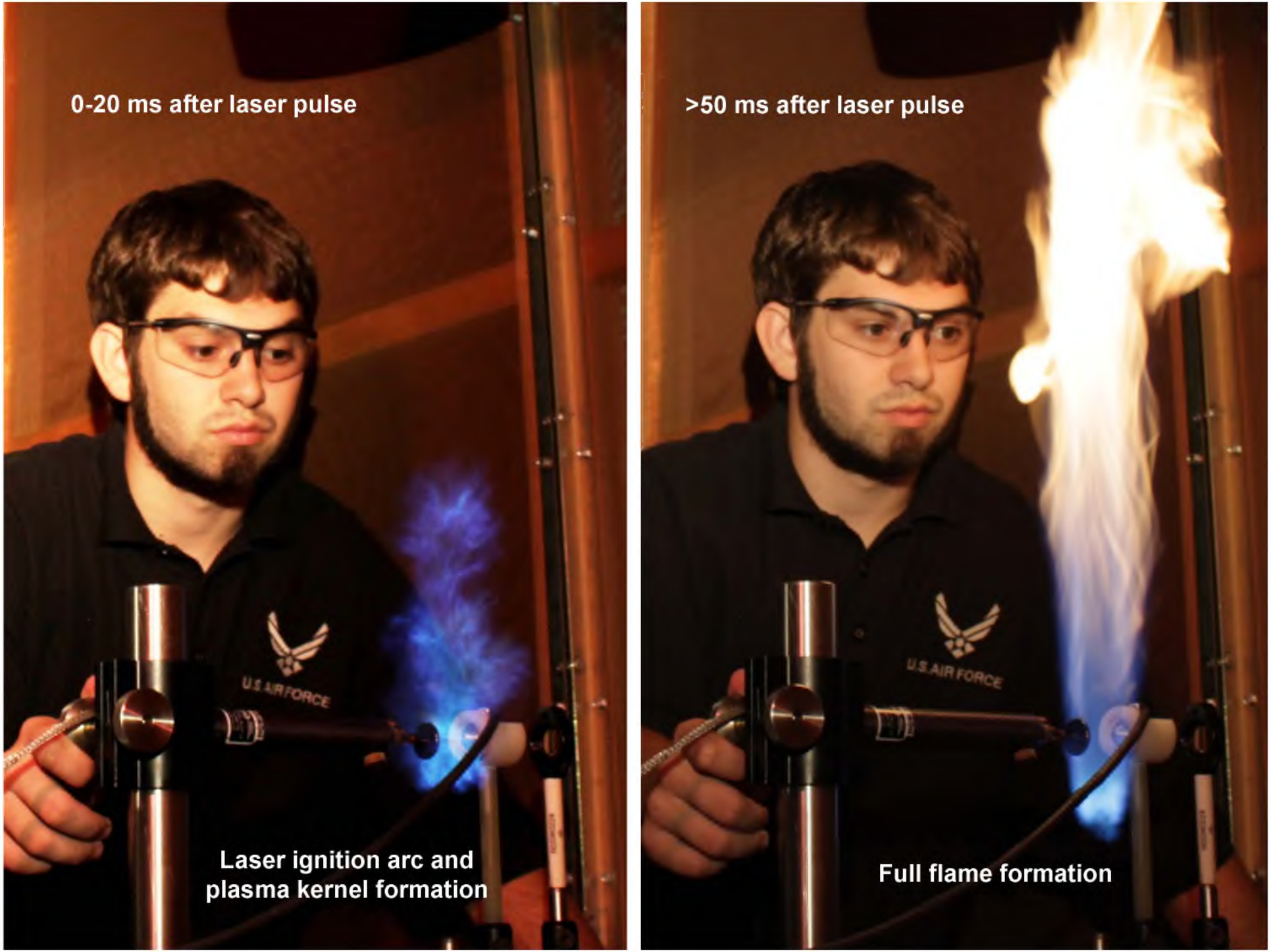
Arc plasma moving with air flow

Arc plasma extinguished

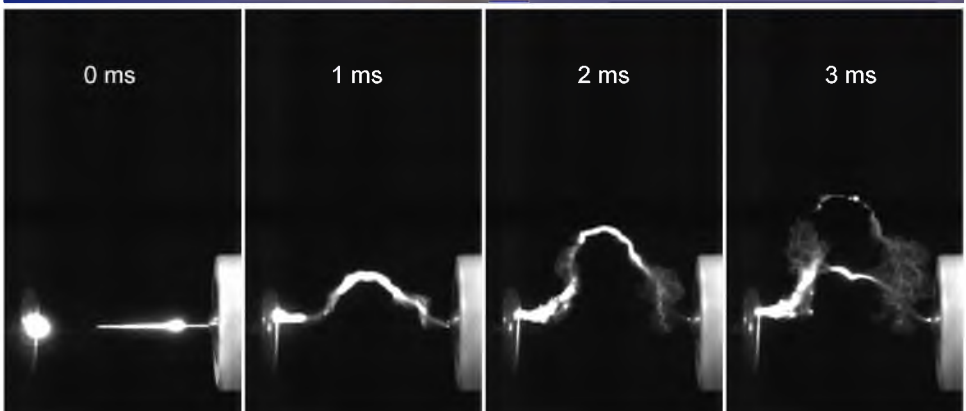
Test of Laser Induced Ignition in Open Fuel – Air Flow

Experiments conducted to test capability to breakdown air and ignite fuel at various electrode gaps and applied voltages




0-20 ms after laser pulse
Laser ignition arc and
plasma kernel formation
>50 ms after laser pulse
Full flame formation

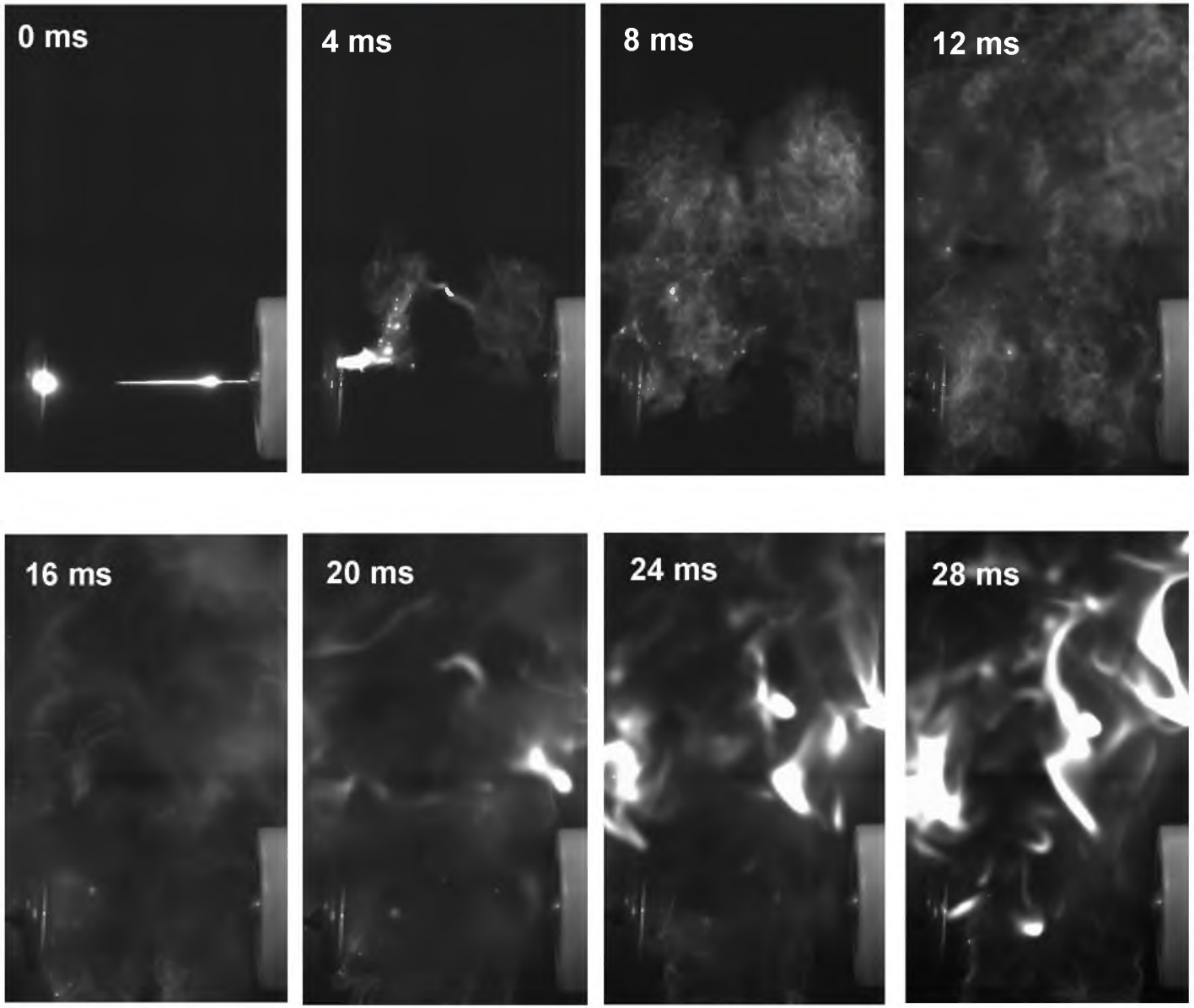
High Speed Frames of Initial Stages of Laser Ignition in Propane-Air Flow at ~30 m/s



Initial arc along laser path	Arc plasma moving with propane-air flow	Plasma kernel expanding	Secondary arc path between ionized gas region

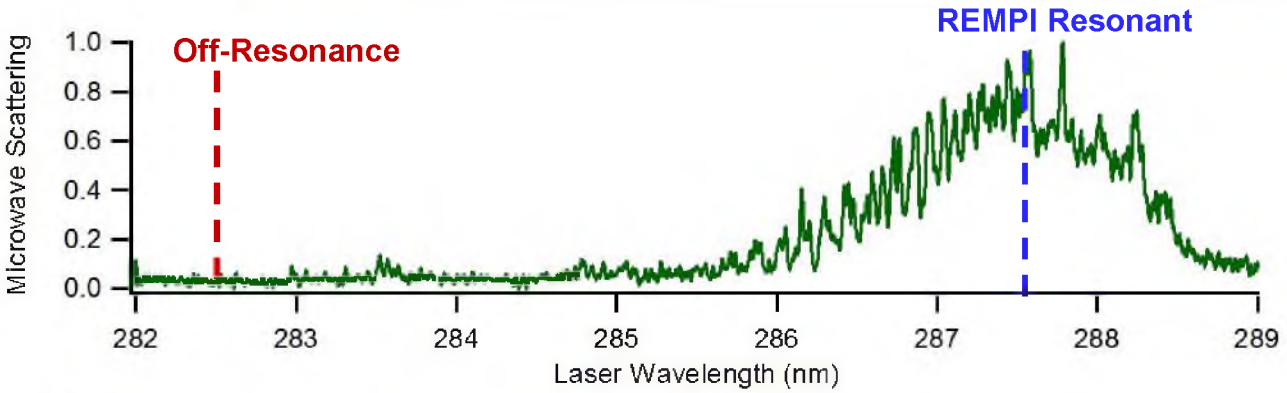
High Speed Video of Laser Ignition and Combustion in Propane-Air Flow

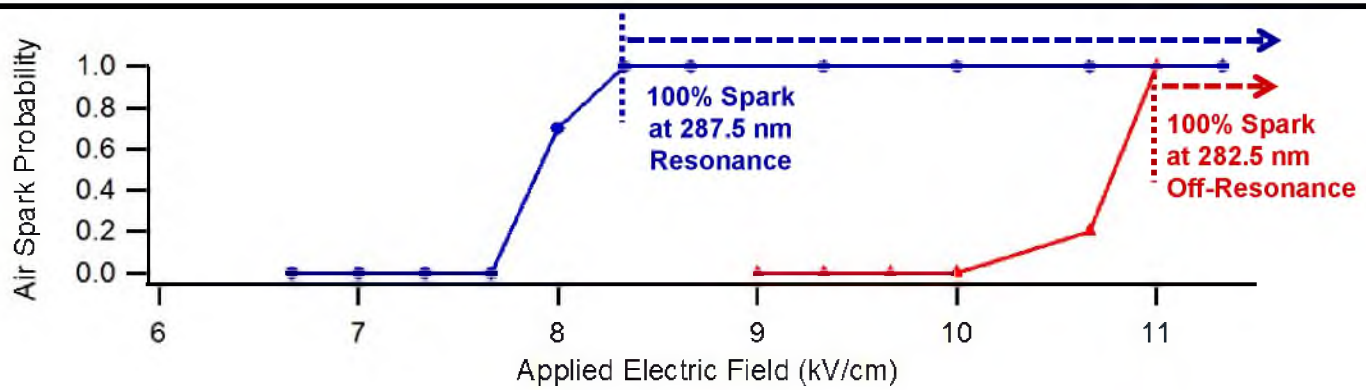
- Video frames following ignition from initial arc through plasma kernel formation
- Plasma kernel expansion leads to full flame combustion



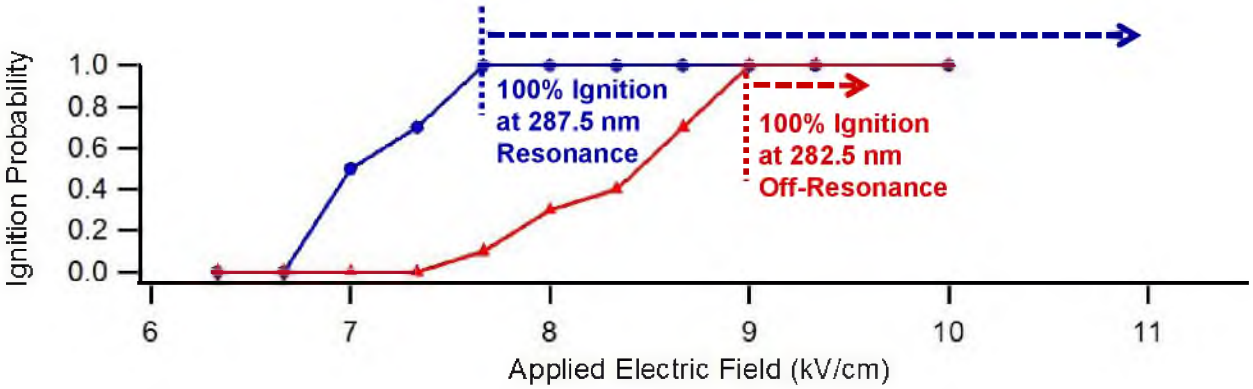
REMPI Laser Ignition verses Off-Resonant Laser Effects

UV Laser wavelength was alternated between
- 287.5 nm (REMPI Resonance)
- 282.5 nm (Off-Resonance)
to quantify the resonant effects



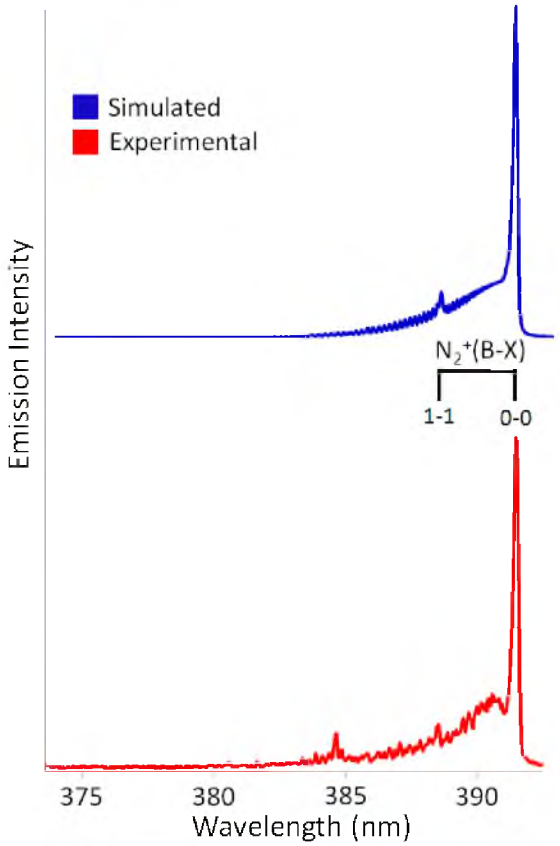


In air, REMPI resonant wavelength has MUCH lower E-field threshold to create a spark

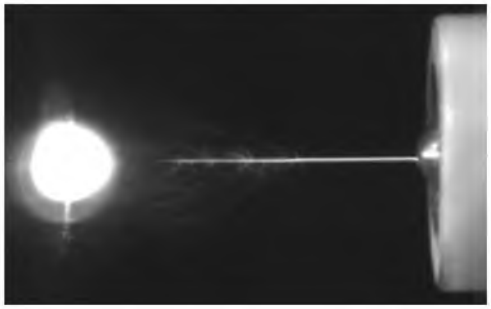


In propane-air mixture, REMPI resonant wavelength has a *slightly* lower E-field threshold for ignition as the presence of fuel tends to enhance off-resonant breakdown effects

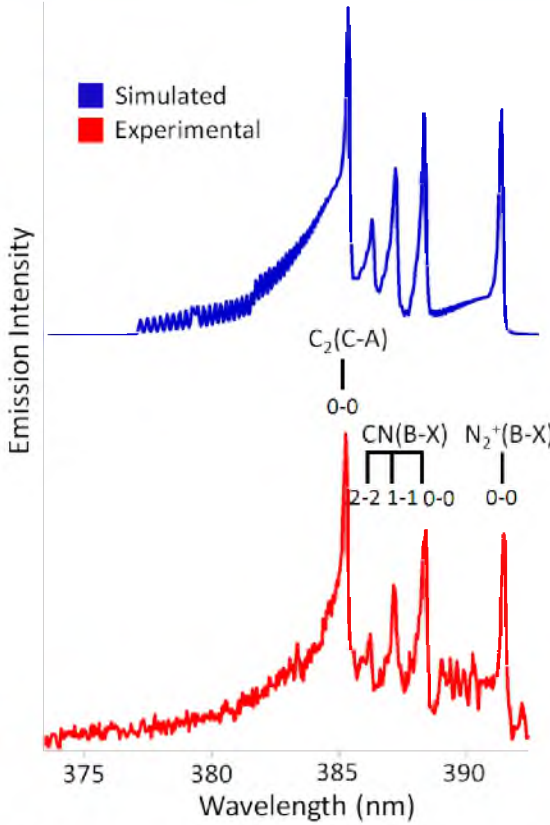
Comparison of Arc Spectra of Air vs. Propane-Air Mixture



Typical emission spectrum in pure air during initial arc at 287.5 nm REMPI resonance



Typical image in pure air during initial arc at 287.5 nm REMPI resonance



Emission spectrum in propane-air during initial arc at 282.5 nm off-resonance

Breakdown of fuel molecules indicated by C_2 and CN bands

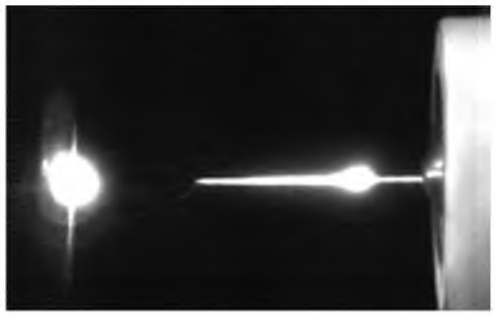


Image of initial arc in propane-air flow shows bright central breakdown (not seen in pure air)

Summary

- Laser-induced breakdown of a moderate-speed air-propane mixture flow has been demonstrated to occur across a high-voltage gap.
- The breakdown is manifested as a pre-ionized micro-plasma path across the electrodes.
- This breakdown scheme could potentially be used to provide ignition within a combustion chamber.
- The REMPI resonant wavelength resulted in a lower E-field threshold for ignition or spark compared to off-resonance.
- Some breakdown effects observed in propane-air with off-resonant wavelength